Hydrodynamic characterisation of an airlift reactor with an enlarged degassing zone, in the presence of non-Newtonian fluids

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Introduction

During the last decade, the airlift as a bioreactor became more and more important. Starting from the production of single-cell protein, now in decline, it has been used for the most various processes, such as waste waters biological treatment, antibiotics, animal and vegetable cell production [1], [2], [3], [4].

Part of the success is, surely, due to its peculiar characteristics, namely the approximately constant and low shear that it generates in the medium (being, therefore, ideal for those cultures less resistant to mechanical damage) [5], [6], [7], its simpler design (easier to build and less prone to contamination), its ease of operation and its need for smaller investments and lower maintenance costs [3], [8], [9].

The presence of an enlarged degassing zone in the top of an airlift reactor strongly affects its hydrodynamic performance [10]. Studies have been made with Newtonian fluids and in the presence of a third (solid) phase [11, 12]. This work intends to characterise the hydrodynamics of such an airlift reactor in the presence of water and a non-Newtonian (pseudo-plastic) fluid, in a two-phase flow.

Materials and Methods

The present work was made using a 60 L capacity internal circulation airlift reactor with an enlarged degassing zone, using non-Newtonian fluids and water.

In order to calculate mixing and circulation times as well as the total gas hold-up and the circulation velocities in the riser and in the downcomer, a pulse of a saturated solution of NaCl was injected near the top of the internal tube of the reactor, measuring the alteration of the conductivity of the fluid by means of a conductivity cell connected to a data acquisition system.

The circulation velocities in the riser and downcomer tubes were measured using a solid flow follower, the density of which was adjusted to be equal to that of the circulating liquid phase. The total gas hold-up was determined measuring the volume of the fluid displaced with each aeration rate.

Experiments were made for several pseudo-plastic fluids (carboxymethyl-cellulose – CMC – aqueous solutions with several concentrations: 0.125 %, 0.250 % and 0.375 % in weight) and a Newtonian fluid (water), at several aeration rates (from 5 to 24 standard litres per minute – slpm).

Results and discussion

It was possible to correlate the circulation velocity (v) with the aeration rate (G) for each CMC solution for the riser (Figure 1) and downcomer (Figure 2) sections.

Observing Figures 1 and 2 and the correlations presented (in the form of $v = k.e^{(\alpha.G)}$) it can be verified that, in general, the values of k and α follow a regular trend. The former decreases with the increase in the CMC concentration, while for the latter that variation is the opposite.

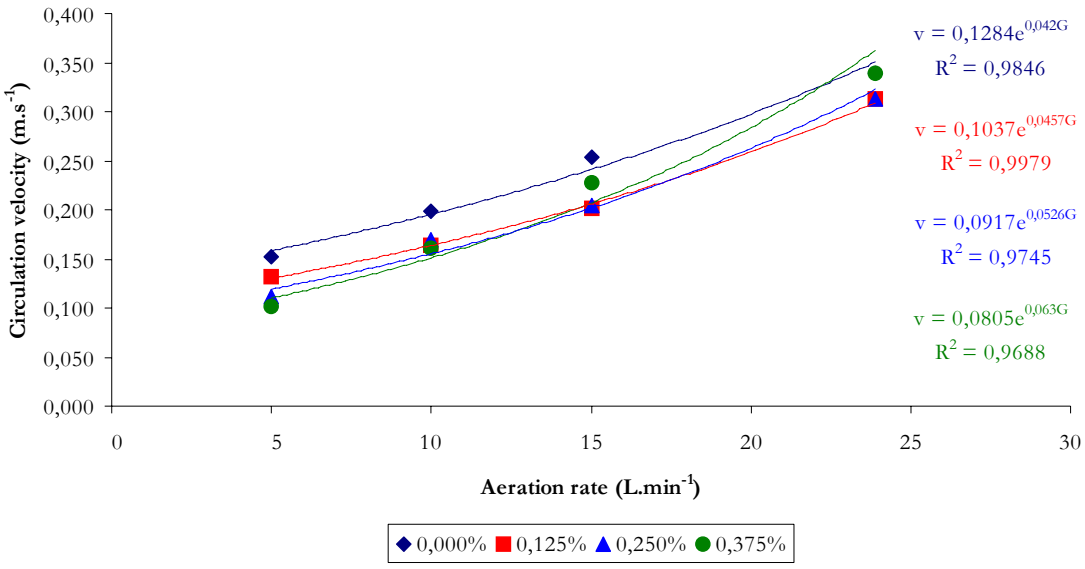

Figure 1: Circulation velocities, v (m.s^{-1}), *versus* aeration rate, G (L.min^{-1}), and the correlation expressions obtained for water and each CMC solution, for the riser section (from top to bottom, corresponding to water and 0.125 %, 0.250 % and 0.375 % CMC solution).

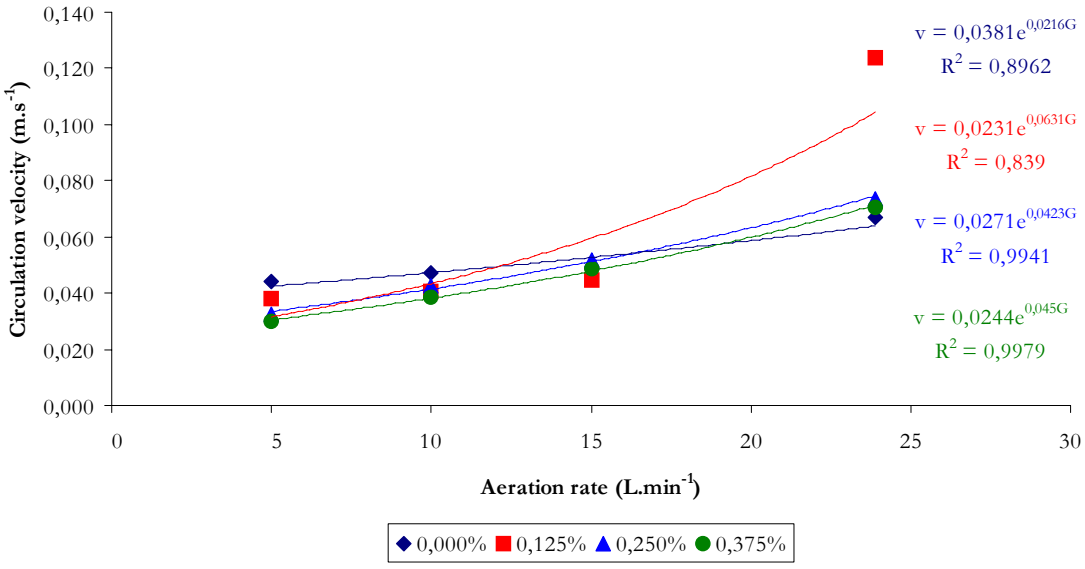

Figure 2: Circulation velocities, v (m.s^{-1}), *versus* aeration rate, G (L.min^{-1}), and the correlation expressions obtained for water and for each CMC solution, for the downcomer section (from top to bottom, corresponding to water and 0.125 %, 0.250 % and 0.375 % CMC solution).

This means that there is an inverse relationship between liquid circulation velocity and liquid (apparent) viscosity (there is an increase of the apparent viscosity with CMC concentration – data not shown), k being the parameter reflecting that relationship. Further, there is a more than proportional increase of the circulation velocity with the increase of the aeration rate, becoming more significant as the viscosity of the solution increases (higher values of α). This can be caused by the bigger air bubbles formed in higher viscosity solutions: the gas holdup increases (see Figure 5), increasing the driving force that is responsible for the circulation inside the reactor.

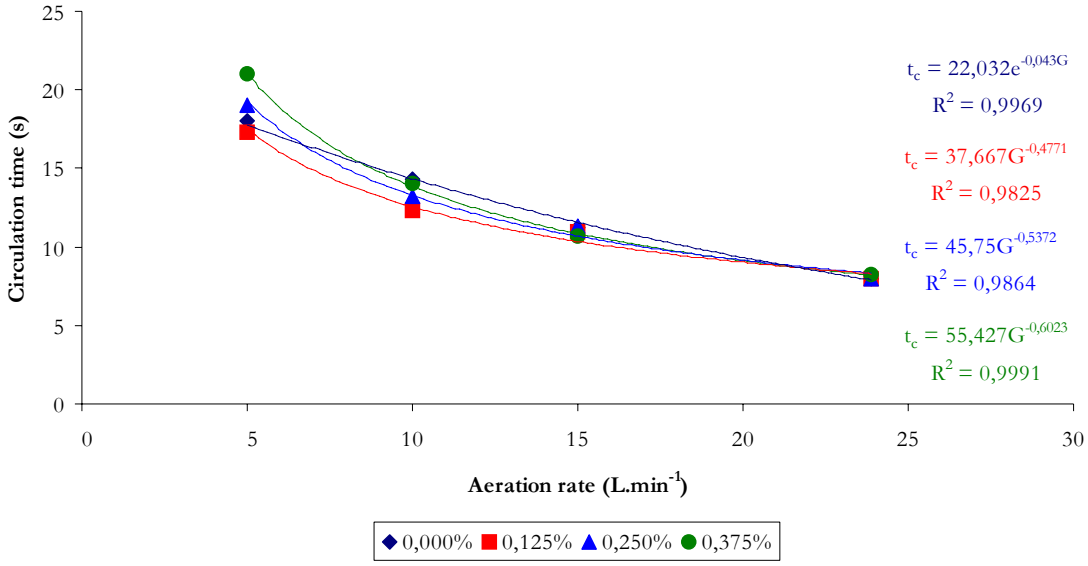

Figure 3: Circulation time, t_c, as a function of the aeration rate, G, for water and for each CMC solution. The correlations obtained are also presented (from top to bottom, corresponding to water and 0.125 %, 0.250 % and 0.375 % CMC solution).

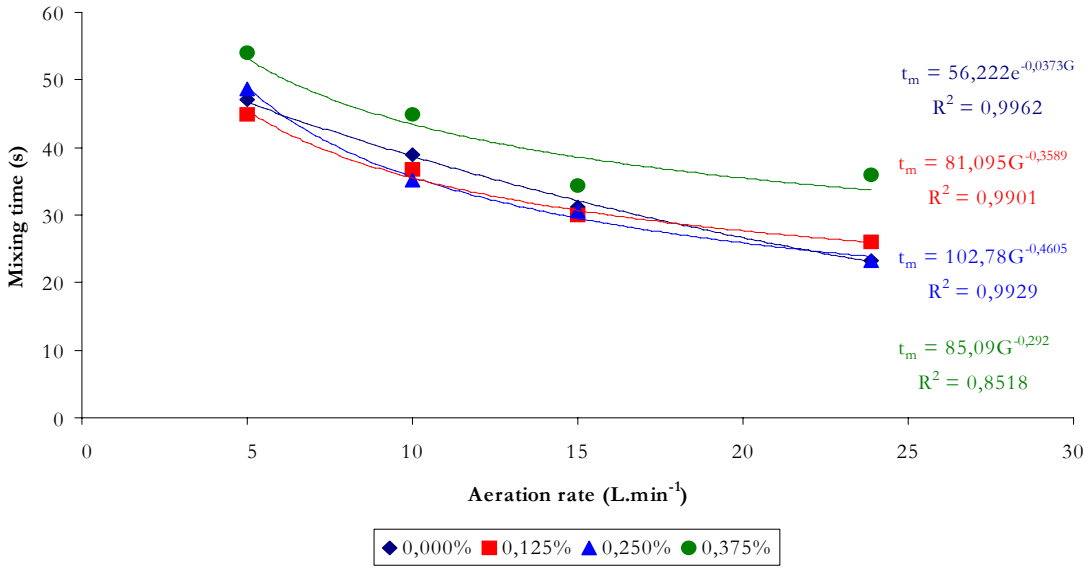

Figure 4: Mixing time, t_m, as a function of the aeration rate, G, for water and for each of the CMC solutions. The obtained correlations can also be seen (from top to bottom, corresponding to water and 0.125 %, 0.250 % and 0.375 % CMC solution).

In Figure 3 it can be verified that the circulation time decreases with the increase in the aeration rate for all of the CMC solutions used. The concentrations of the CMC solutions also play a role, though having a less significant effect: the higher the solution's concentration the higher the circulation time. It can also be observed that with the increase in the aeration rate the behaviour of the solutions approaches that of water, that is, of a Newtonian fluid. The variation of the circulation time with the aeration rate is not linear; in the case of water, however, the closeness to the linearity is noteworthy.

Mixing time has the same trend of the circulation time, as it can be seen in Figure 4. For CMC solutions with a concentration of 0,275% or less, mixing time approaches that of water. The solution with a concentration of 0,375% CMC shows higher mixing times, which can be explained by the divergence of this solution's behaviour from a Newtonian one.

The trends of mixing and circulation times were expected, given the results obtained for the circulation velocity, reflecting the dependence of the former parameters from the latter.

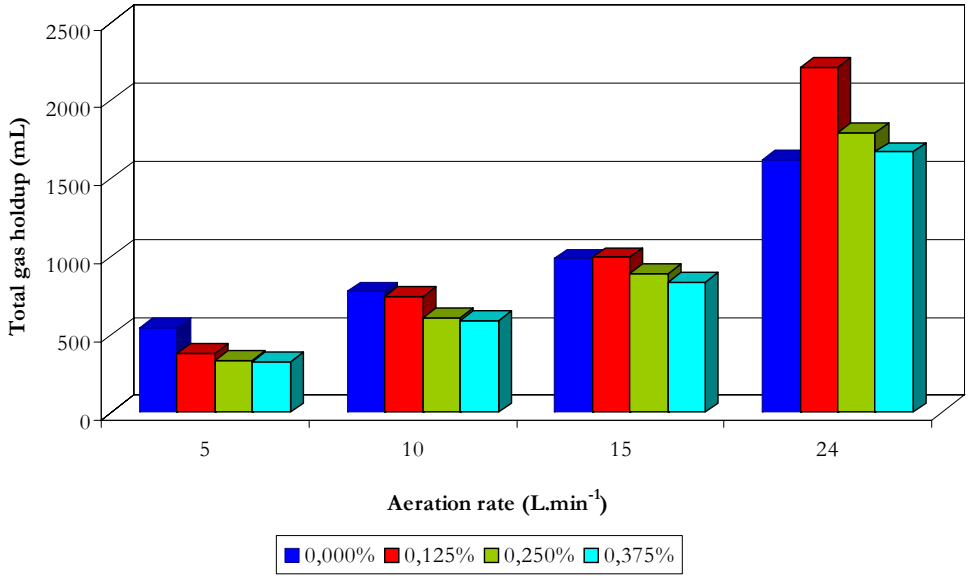

Figure 5: Total gas hold-up *versus* aeration rate, for the various CMC solutions.

Analysing Figure 5 it can be seen that for all CMC solutions and for water the total gas hold-up increases with the increase of the aeration rate. Nevertheless that increase is greater for the CMC solutions than for water due to the increase in the fluid's viscosity. In fact, more viscous fluids make the air bubbles' disengagement more difficult at the top section, leading to a higher air recirculation into the downcomer. This effect is less pronounced for water owing to its lower viscosity when compared to that of the CMC solutions.

Two possible explanations for the decrease in the total gas hold-up with the increase of the CMC concentration for a given aeration rate are, on one hand, the lower fluid velocity inside the reactor, which causes less air being dragged to the downcomer section and, on the other hand, the formation of bigger bubbles for the solutions having a higher CMC concentration, which have higher rising velocities, leading to a more efficient release in the degassing section.

With this work it was possible to obtain correlations for the various parameters involved, namely the mixing and circulation times as a function of the aeration rate for the various fluids used, and for the circulation velocity in the riser and downcomer sections also as a

function of the aeration rate. Further, the influence of the aeration rate on the total gas holdup was also determined for the various fluids used.

This work shall continue with the characterization of this type of reactor in the presence of non-Newtonian fluids and a third (solid) phase. The determination of the gas hold-up in the riser and downcomer sections, separately, as well as in the degassing section, can also be performed in order to obtain some parameters (such as the Bodenstein number, *Bo*) that could not be obtained in the present work.

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